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A NEW PENETRATION NEEDLE FOR USE IN TESTING BITUMINOUS MATERIALS

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During the early period of the bituminous paving industry the asphaltic cement was usually tested by chewing a small piece and judging its consistency by its resistance to the teeth. With the development of the industry and specifications for work of this character it soon became evident that some more definite method of determining and defining consistency must be evolved, and in 1889 H. C. Bowen, of Columbia University, first described [1] a machine for the purpose. This was followed some years later by the machines designed by A. W. Dow [2] and by Richardson and Forrest.[3]

All of these machines had for their basic principle the depth to which a No. 2 sewing needle would penetrate the material under certain specified conditions of load, time, and temperature. Most, if not all, needle manufacturers produce No. 2 sewing needles, all makes of which are not necessarily of the same shape and size. Since it has, however, been generally understood that the No. 2 needle manufactured by R. J. Roberts was that most often used for the selection of standard needles, the subcommittee of the American Society for Testing Materials which has the penetration test under investigation made the following recommendation in 1915: [4]

The needles for this test shall be R. J. Robert's Parabola Sharps No. 2. They shall be carefully selected by the use of a hand glass, rejecting all that are manifestly of unusual shape or taper. Needles thus selected shall be compared with a standard

[1] Bowen, H. C. An apparatus for determining the relative degree of cohesion of a semi-liquid body. *In* School Mines Quart., v. 10, no. 4, p. 297–302, 2 fig. 1889.

[2] Dow, A. W. The testing of bitumens for paving purposes. *In* Amer. Soc. Testing Materials, Proc. 6th Ann. Meeting, 1903, v. 3, p. 354. 1903.

[3] Richardson, Clifford, and Forrest, C. N. The development of the penetrometer as used in the determination of the consistency of semi-solid bitumens. *In* Amer. Soc. Testing Materials, Proc. 10th Ann. Meeting, 1907, v. 7, p. 626–631, 3 fig. 1907. Discussion, p. 632–637.

[4] Report of sub-committee on penetration. *In* Amer. Soc. Testing Materials, Proc. 18th Ann. Meeting, 1915, v. 15, pt. 1, p. 353. 1915.

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needle and further rejections made of those which vary more than one point from that obtained with the standard needle, on a sample having a penetration of approximately 60.

The committee further stated that it did not think it advisable to recommend at the present time a standard needle for reference, deferring such action until the next annual meeting of the society. Until such recommendation is made needles furnished with penetration machines are to be considered standard.

The above-recommended practice is representative of the method for selecting needles which has been followed in the Office of Public Roads and Rural Engineering, and the standard used for comparison and selection was a needle originally supplied with the penetration machine in use. It has been, however, not uncommon practice in certain laboratories to purchase a package of No. 2 needles and to use them on the assumption that they possessed the requisite dimensions and shape. In an effort to prove the fallacy of such an assumption the authors have taken an enlarged photograph of a package of Roberts's No. 2 needles, an examination of which will serve to make clear the ordinary variations in point, shape, and taper (Pl. LXXXII, fig. 1).

These variations are more clearly shown through a consideration of the results obtained in selecting needles to be used for routine testing in the office. Several packages were first sorted with the aid of a magnifying glass and micrometer caliper, and a selection made of those whose shape and size appeared to be identical with the shape and size of the standard. From a lot of 72 needles, only 12 were thus selected. From these 12, those were selected for use which gave practically identical results in the penetrometer with a so-called standard needle on two samples of oil asphalt. The results of these tests are given in Table I, from which it may be seen that only 5 of the 12 needles fulfilled the requirements. Needles that failed to give accepted values on the harder materials were not tried on the softer.

Inasmuch as only 5 needles out of 72 proved acceptable, it may be seen what results would follow from the indiscriminate use of No. 2 needles as such.

It is further to be noted particularly that there is no existing single standard with which comparison can be made, owing to the fact that there is no means of accurately defining or gauging the type of needle in use. The work herein described was undertaken for the purpose of devising, if possible, a needle which would give results practically identical with results now obtained in using the so-called standard needles, and which could be accurately described and duplicated at any time.

The standard needle on file in the office is 1.8 inches in length, with a diameter of 0.040 inch for a length of 1 inch from the eye. The remainder of the needle tapers in a parabolic curve to a sharp point. The simplest

needle to define would be one having a straight taper. Round, polished, annealed-steel drill rods having diameters of 0.042 inch were therefore cut into 2-inch lengths and pointed at one end with tapers having a length of $\frac{3}{16}$, ¼, $\frac{5}{16}$, and ⅜ inch. Each needle was tempered and highly polished, then tested in the penetrometer on a material showing a penetration of 140 with the standard needle. The penetrations were as follows on needles made from 0.042-inch drill rod: $\frac{3}{16}$-inch taper, 125; ¼-inch taper, 127; $\frac{5}{16}$-inch taper, 129; ⅜-inch taper, 134.

TABLE I.—*Results of a standardization test of penetration needles on oil asphalt*

[Accepted values 6.8, 6.9, 7.0]

Needle No.	Oil asphalt 1.					Oil asphalt 2.	
	Operator C.	Operator F.	Operator D.	Operator A.	Operator E.	Operator C.	Operator F.
Standard	6.9	6.9	6.9	7.0	7.0	15.9 15.6	15.7 15.6
1 (rejected)	7.2	7.3	....	....	....	....	....
2 (O. K.)	6.8	6.6	....	....	6.8 6.9	15.9	15.9
3 (O. K.)	6.9	6.7	....	6.85	....	15.8	15.8
4 (rejected)	7.1	7.4	....	....	....	....	....
5 (rejected)	7.1	7.0	....	....	7.1	....	....
6 (O. K.)	6.7 6.7	6.95 6.95	6.8	6.95	....	15.9	15.9
7 (rejected)	6.8	6.6	....	6.55 6.3	....	....	....
8 (rejected)	6.9	6.5	....	....	6.7	....	....
9 (rejected)	6.8 6.7	6.6	....	6.55	....	....	....
10 (O. K.)	6.9	6.75 6.75	....	....	6.8	16.0	16.0
11 (O. K.)	6.9	6.85	....	....	....	15.9 16.0	16.0
12 (rejected)	6.8	6.6	....	....	6.4 6.75	....	....

While none of these needles yielded as high results as the standard, the one showing the highest values was tested on a sample of material having a penetration of 95 with the standard needle. A penetration of 103 was obtained. This eliminated the 0.042-inch drill rod from further consider-tion, since it was evident that a taper which would check with the standard needle on softer materials would give higher results than the standard on harder materials.

Drill rod with a diameter of 0.041 inch was then tried. This actually measured 0.0405 inch, and the finished and polished needle from it had a diameter of 0.040 inch. Three pieces of that diameter were given tapers of $\frac{3}{16}$, ¼, and $\frac{5}{16}$ inch, respectively, then polished and tested in comparison with the standard needle. The results on four samples of bituminous materials are given in Table II.

TABLE II.—*Results of an asphalt penetration test with a needle made from a steel drill rod 0.041 inch in diameter*

Taper of needles.	Sample No. 5284 (blown oil asphalt).	Sample No. 5963 (oil asphalt).	Sample No. 5985 (blown oil asphalt).	Sample No. 8928 (fluxed native asphalt).
Standard	30	153	75	109
3/16-inch taper	30	148	70	106
1/4-inch taper	32	150	74	109
5/16-inch taper	34	153	80	112

It will be noted from the above that on all four samples, representing three different types of material, the needle with 1/4-inch taper gave results in comparatively closer accord with those obtained by the standard needle than did the others. Three new needles of this type were therefore made and tested in comparison with the standard needle on various types of bituminous material having a wide range of penetration. The results are given in Table III. When it was found that all three needles checked with the standard throughout, the No. 1 new needle was run comparatively with the standard on six additional products, covering a still wider range of materials, in order to determine whether products varying in their general adhesive character might have any effect on the results. It will be noted by referring to Table III that the needle which the writers have designed yields in all cases results practically identical with those obtained with the standard needle. In cases where no results are given for the No. 3 needle the omission is due to the fact that the samples were run before the third needle had been prepared. In all cases but one the results are given by two operators.

TABLE III.—*Results of a comparative test of the new penetration needle with a standard needle*

Sample No.	Material.	Standard needle.		Needle No. 1.		Needle No. 2.		Needle No. 3.	
		Operator A.	Operator B.	Operator A.	Operator B.	Operator A.	Operator B.	Operator A.	Operator B.
5959	Blown Texas oil asphalt	8	8	9	9	8	8	......	......
5284	....do	30	31	32	32	32	32	......	......
8233	Mexican oil asphalt	41.5	41.5	43	41.5	41	41	......	......
8961	California oil asphalt	49	47	47	48	48	49	49	47
6811	Texas oil asphalt	77	76	77	78	76	76	......	......
8016	....do	93	92	95	95	93	93	......	......
8962	California oil asphalt	94	94	94	94	93	93	94	94
6291	Texas oil asphalt	108	110	110	110	109	108	......	......
5406	Oil asphalt (cut-back)	114	114	111	111	114	114	113	112
8966	Mexican oil asphalt	118	121	118	120	117	117	117	119
8970	....do	119	118	117	119	119	119	118	119
8963	California oil asphalt	135	133	134	133	135	133	135	136
5381	Oil asphalt (cut-back)	133	134	135	135	135	135	134	135
5963	Texas oil asphalt	151.5	150	150	151	151.5	151	......	......
5559	Oil asphalt (cut-back)	168	170	170	170	170	168	170	169
8963A	Fluxed California asphalt	192	193	192	194	195	196	195	193
8963B	....do	236	239	235	236	234	238	233	234
8963C	....do	292	295	295	......	295	......	291	......
5118	Fluxed Trinidad asphalt	83	85	83	85	......	......	......	......
5119	Fluxed Cuban asphalt	65	65	65	67	......	......	......	......
8326	Fluxed Bermudez asphalt	45	46	46	46	......	......	......	......
8615	....do	113	115	113	115	......	......	......	......
6293	Blown Gilsonite oil asphalt	140	140	138	138	......	......	......	......
5104	....do	60	60	59	60	......	......	......	......

About the time this work was completed, a second standard needle was obtained from the same source as the one used in the foregoing tests. In order to determine the accuracy with which a number of the new type of needle could be readily made, seven were prepared and checked against both the old and new standard on two distinct types of bituminous material. The results are given in Table IV. Each result is an average of at least three determinations.

TABLE IV.—*Results of a comparative test of new and old standard penetration needles and seven others of the new type*

Needle.	Sample No. 8957 (Gilsonite blown oil asphalt).	Sample No. 8962 (California asphalt).	Needle.	Sample No. 8957 (Gilsonite blown oil asphalt).	Sample No. 8962 (California asphalt).
New standard....	94	96	Needle No. 4......	92	96
Old standard.....	91	96	Needle No. 5......	91	96
Needle No. 1......	89	94	Needle No. 6......	91	96
Needle No. 2......	90	97	Needle No. 7......	90	95
Needle No. 3......	91	95			

It will be noted from the above that all seven new needles check very closely with the old standard needle on both samples, and that on sample 8957 they check closer with the old standard than do the two standards with one another. The lack of uniformity in the shape of the two standard needles, the uniformity of the new type of needle, and the relative shapes of the old and new forms of needle are shown in Plate LXXXIII, figure 2, which is a reproduction of an enlarged photograph of the two standard and seven new needles referred to in Table IV.

The following conclusions are offered as a result of the above investigation:

(1) That the No. 2 sewing needle which has heretofore been used for the penetration test can not be taken indiscriminately, but must be carefully selected and standardized.

(2) That there is no recognized established standard with which new needles can be compared, and that it is not feasible to accurately describe the dimensions of a parabola needle.

(3) That the so-called standard needles furnished with penetration machines may vary among themselves.

(4) That the writers have designed a needle which gives results in close accord with existing standards and has, moreover, the advantage of being accurately described and easily reproduced.

(5) The needle is made by placing a 2-inch length of 0.041-inch annealed-steel drill rod in the chuck of a high-speed lathe, and by means of a fine sharp file turning the end to a sharp point having a ¼-inch taper. When it has been made as smooth and sharp as possible by this means,

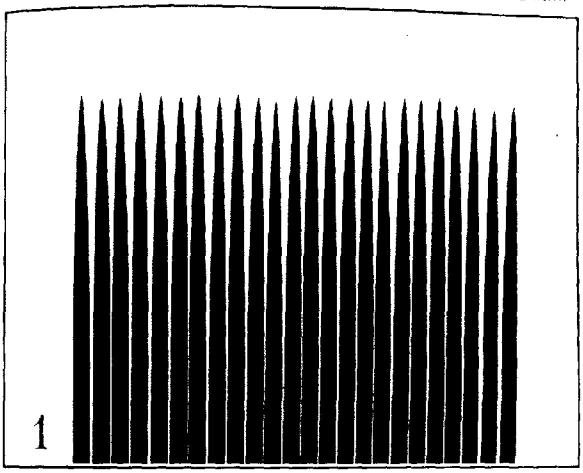
the needle is tempered,[1] then ground to a sharp point with a good stone, after which it is smoothed and polished with emery dust, crocus cloth, and rouge, and finally held carefully on a buffing wheel. The finished needle should be sufficiently smooth and sharp to enter and pass through a piece of ordinary writing paper without sticking or friction. In other words, this new needle must have as sharp a point and smooth a surface as any sewing needle. The important thing is to have the taper straight, beginning ¼ inch from the end, and the needle above the taper exactly 0.04 inch in diameter.

[1] The tempering solution consisted of 5 teacupfuls of common salt, 6 ounces of saltpeter, 12 teaspoonfuls of powdered alum, and 1 teaspoonful of corrosive sublimate dissolved in 10 gallons of water. The needle was tempered by heating carefully to a dull white heat and plunging at once into the tempering solution. It was then lightly cleaned with smooth emery cloth, heated carefully to a point below dull redness, and again plunged into the solution.

PLATE LXXXII

Fig. 1.—Direct enlargement of a package of No. 2 sewing needles, showing the variations in shape.

Fig. 2.—Direct enlargement of penetration needles, showing the comparison between two standard needles (1-S, 2-S) and seven needles of the new type prepared by the writers.



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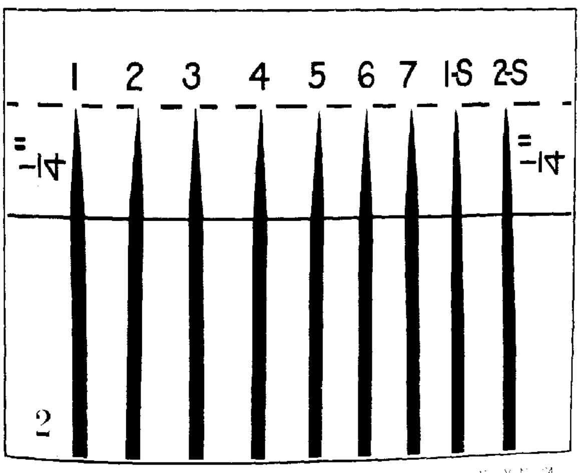

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A NEW IRRIGATION WEIR[1]

By V. M. Cone,

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INTRODUCTION

The accurate measurement of water delivered to the irrigator has been retarded by lack of information concerning devices adapted to the various conditions of size and grade of canals, and to the sand and silt troubles encountered throughout the West. These conditions are so varied that it is very improbable that any one type of measuring device will be desirable or practicable for all cases. Although the weir is the principal measuring device in use in the West, there are many places where the common types of weirs can not be used, and consequently water users are either making current-meter measurements occasionally or systematically or are doing without any measurement.

Many attempts have been made to devise a weir that would be simple and inexpensive in construction, free from sand troubles, and accurate and simple in operation; but usually what has been gained in one direction has been lost in another.

Weirs with full contractions have been built in many places where sand and silt accumulations have resulted in inaccurate measurements, or constant attention has been required to keep the weir box clean. The first cost of such a weir is rather high and the nuisance and expense of keeping it clean often make it undesirable. In an attempt to overcome these objections many weirs have been built with incomplete contractions which have caused the water to pass through the weir box at a velocity sufficiently high to necessitate the addition of a correction factor to the discharge table, but not high enough to completely prevent the accumulation of sand. It usually occurs that full-contraction-weir tables without correction are used with the modified weirs, and therefore the measurement is not worth much more than the guess of an experienced ditch rider. Damage has resulted from the prevalent belief that the weirs in general carry the stamp of accuracy. Under proper conditions of construction and operation, full-contracted weirs are accurate within a small percentage,[2] but such conditions are not always to be found in the field. In the literature of hydraulics there are practically no records of

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[1] The work on which this paper is based was done in the hydraulic laboratory, at Fort Collins, Colo., under a cooperative agreement between the Office of Experiment Stations, United States Department of Agriculture, and the Colorado Agricultural Experiment Station.

[2] Cone, V. M. Flow through weir notches with thin edges and full contractions. *In* Jour. Agr. Research, v. 5, no. 23, p. 1051–1114, 1916.

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experiments with weirs having completely suppressed bottom contraction. The idea previously considered seems to have been the suppression of the end contractions in order to secure a simple discharge formula, but such an arrangement of weir box possesses many of the objectionable features of full-contracted weirs. Discharge formulas are infrequently used in the field, tables usually being available, and it therefore seems preferable to have a weir that is practicable and of permanent accuracy rather than to complicate the weir-box conditions in order to simplify the discharge formula.

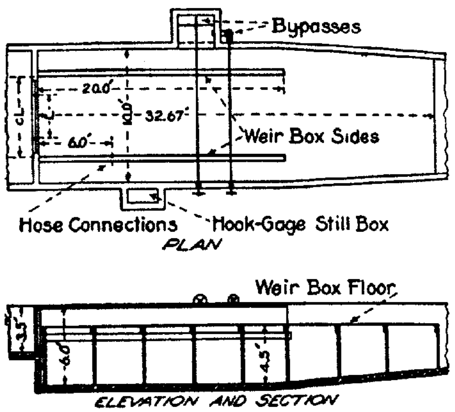

Fig. 1.—Plan, elevation, and section of concrete weir box in the hydraulic laboratory of the Colorado Experiment Station; also arrangement of experimental weir section for Nos. 1 to 6 and 13 to 16, in Table I.

A series of experiments was made in the hydraulic laboratory at Fort Collins, Colo., during the summer of 1914, for the purpose of developing a weir that would be self-cleaning, require a minimum amount of labor and material for construction, measure discharges with an accuracy commensurate with field conditions and irrigation demands, and be easily operated by the ordinary man, which means that only simple readings without any computations would be required to determine the discharge.

ARRANGEMENT OF APPARATUS FOR EXPERIMENTS WITH NEW TYPE OF WEIR [1]

In the permanent concrete weir box, which is 10 feet wide and 6 feet deep, a wood floor was built of tongue-and-groove lumber (fig. 1). The wood floor was about 4.5 feet above the concrete floor and was water-tight and level throughout. Its length was 20 feet for four sets of experiments, but it was extended to 32.67 feet for all other experiments. The sides of the temporary weir box were made of single widths of boards set in a vertical position, but arranged to be moved to any position or any angle and rigidly fastened to the floor. The several arrangements of the weir box are given in Table I, and figures 1 to 13, inclusive.

[1] For a description of the hydraulic laboratory and equipment, see Cone, V. M., op. cit., and Cone, V. M., Hydraulic laboratory for irrigation investigations, Fort Collins, Colo. *In* Engin. News, v. 70, no. 14, p. 662–665, 5 fig., 1913.

Table I.—*Effect of size and shape of weir box on discharge*[1]

SPECIAL TESTS

No.	Length of weir crest.	Width of weir box at crest.	Width of weir box at 20 feet.	Equation of discharge curve.	Fig. No.	Length of floor.	Remarks.
	Feet.					*Feet.*	
1	1	1½ L	1½ L	$Q=4.641\ LH^{1.575}$.....	1	32.67	Sides parallel, no wings.
2	1	2 L	2 L	$Q=3.768\ LH^{1.522}$.....	1	32.67	Do.
3	1	3 L	3 L	$Q=3.441\ LH^{1.498}$.....	1	32.67	Do.
4	1	4 L	4 L	$Q=3.343\ LH^{1.439}$.....	1	32.67	Do.
5	1	5 L	5 L	$Q=3.316\ LH^{1.484}$.....	1	32.67	Do.
6	1	6 L	6 L	$Q=3.274\ LH^{1.479}$.....	1	32.67	Do.
7	1	2 L	3 L	$Q=3.72\ LH^{1.627}$......	2	32.67	Sides extended at same angle to distance of 32.5 feet from crest.
8	1	2 L	3 L	$Q=3.69\ LH^{1.508}$......	3	32.67	Sides extended to sides of concrete box at angle of 45° to axis.
9	1	2 L	3 L	$Q=3.71\ LH^{1.522}$......	4	32.67	Sides extended to sides of concrete box at angle of 90° to axis.
10	1	2 L	2½ L	$Q=3.73\ LH^{1.516}$......	4	32.67	Do.
11	1	2 L	2½ L	$Q=3.73\ LH^{1.510}$......	3	32.67	Sides extended to sides of concrete box at angle of 45° to axis.
12	1.5	2 L	3 L	$Q=3.64\ LH^{1.523}$......	2	....	Sides extended at same angle to distance of 32.5 feet from crest.
13	2	1½ L	1½ L	$Q=4.375\ LH^{1.638}$.....	1	32.67	Sides parallel, no wings.
14	2	2 L	2 L	$Q=3.749\ LH^{1.563}$.....	1	32.67	Do.
15	2	2½ L	2½ L	$Q=3.552\ LH^{1.538}$.....	1	32.67	Do.
16	2	3 L	3 L	$Q=3.439\ LH^{1.535}$.....	1	32.67	Do.
17	2	2 L	2 L	$Q=3.749\ LH^{1.546}$.....	5	32.67	Sides parallel, with 45° wings connecting parallel sides 12 feet long, 3 L apart.
18	2	2 L	3 L	$Q=3.63\ LH^{1.549}$......	2	32.67	Sides extended at same angle to distance of 32.5 feet from crest.
19	3	2 L	2½ L	$Q=3.640\ LH^{1.560}$.....	6	32.67	Sides extended 12 feet parallel to axis and 2½ L apart.
20	3	2 L	3 L	$Q=3.604\ LH^{1.580}$.....	2	32.67	Sides extended about 5 feet at same angle to sides of concrete box.
21	4	1¼ L	1¼ L	$Q=5.327\ LH^{1.698}$.....	7	20.00	Sides parallel, no wings.
22	4	1½ L	1½ L	$Q=4.105\ LH^{1.599}$.....	7	20.00	Do.
23	4	1½ L	1½ L	$Q=4.053\ LH^{1.634}$.....	2	32.67	Sides parallel, extended to distance of 32.5 feet from crest.
24	4	1¾ L	1¾ L	$Q=3.839\ LH^{1.568}$.....	7	20.00	Sides parallel, no wings.
25	4	2 L	2 L	$Q=3.599\ LH^{1.567}$.....	7	20.00	Do.
26	4	2 L	2 L	$Q=3.590\ LH^{1.580}$.....	2	32.67	Sides parallel, extended to distance of 32.5 feet from crest.
27	4	2 L	2 L	$Q=3.714\ LH^{1.570}$.....	8	32.67	Sides parallel, with 45° wings extending to sides of concrete box.
28	4	2 L	2 L	$Q=3.642\ LH^{1.542}$.....	9	32.67	Sides parallel, with 90° wings extending to sides of concrete box.
29	4	2½ L	2½ L	$Q=3.403\ LH^{1.560}$.....	10	32.67	Full width of concrete box.

STANDARD TESTS

30	1	2 L	2½ L	$Q=3.771\ LH^{1.53}$......	2	32.67	Sides extended at same angle to distance of 32.5 feet from crest.
31	1.5	2 L	2½ L	$Q=3.720\ LH^{1.54}$......	2	32.67	Do.
32	2	2 L	2½ L	$Q=3.690\ LH^{1.54}$......	2	32.67	Do.
33	3	2 L	2½ L	$Q=3.630\ LH^{1.55}$......	2	32.67	Do.
34	4	2 L	2½ L	$Q=3.570\ LH^{1.56}$......	2	32.67	Sides extended at same angle to sides of concrete box.

SPECIAL NOTCH TESTS

	Degrees.	*Feet.*	*Feet.*				
35	90	10	10	$Q=2.541\ H^{2.492}$......	11	32.67	No sides, channel full width of concrete box.
36	90	3	7	$Q=2.667\ H^{2.521}$......	12	32.67	Sides extended about 10 feet at same angle to sides of concrete box.
37	90	3	....	$Q=2.679\ H^{2.517}$......	13	32.67	Sides 5 feet apart at 10 feet, then extended 12 feet parallel to axis.

[1] Level wood floor placed about 4.5 feet above floor of concrete weir box; angle iron weir crest.

Steel weir plates having rectangular crests and sides made of brass, with nominal crest lengths of 1, 1.5, 2, 3, and 4 feet, were successively attached to the steel frame anchored in the concrete wall. A 2-inch angle iron, dressed and trued, was set flush in the floor section, and by means of bolts the floor section was drawn tightly against the weir plate. The angle iron formed the crest of the weir and it was sufficiently rigid to prevent any trouble due to the possible warping of the floor, and also insured the crests remaining at the same elevation as the floor. The water passed through the weir notch with full lateral expansion and complete aeration of nappe.

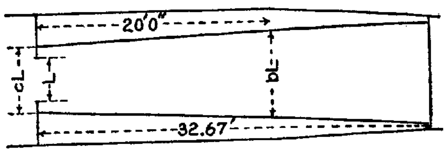

FIG. 2.—Plan of experimental weir box for Nos. 7, 12, 18, 20, and 30 to 34 in Table I.

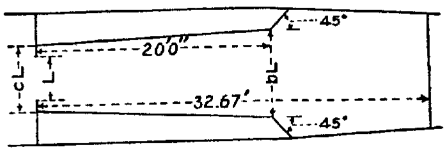

FIG. 3.—Plan of experimental weir box for Nos. 8 and 11, Table I.

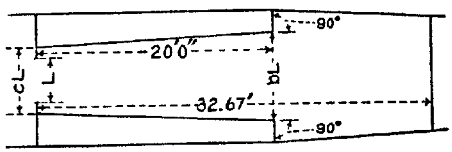

FIG. 4.—Plan of experimental weir box for Nos. 9 and 10, Table I.

The head was determined in the concrete hook-gauge still box which was connected to the weir box by four pieces of ¾-inch hose attached to 1-inch pipe nipples screwed upward through the floor until flush with the surface. The auger holes into which the pipes were screwed were placed near the side of the weir box in a line 6 feet back from the plane of the weir. A second hook gauge was placed in a temporary still box connected by a hose through the side of the weir box near the floor line. This hook gauge was used for check purposes and to determine whether any discrepancies would be introduced by applying the results of the experiments to future installations where the head would be communicated to a still box by pipes through the side of the weir box. The two sets of hook-gauge readings indicated that no error is introduced thereby, provided the pipes are installed at the proper distance from the weir, 6 feet, and in a position normal to the side of the weir box rather than normal to the axis, because the lines of flow are parallel to the side.

In all these experiments the weir discharges were determined volumetrically in the calibrated concrete tanks.

Several series of preliminary experiments were made in order to determine the influence upon the discharge caused by various end contrac-

ion distances, lengths of weir box, contraction wings at entrance of weir ox, and angle of sides of weir box. From these data a set of conditions was chosen to be the standard for the new type of weir, for it is obviously necessary that the weir box be definitely standardized in order that the specifications be duplicated in future installations if the formula and tables are to apply. The terms "standard tests" or "standard conditions" will be used to express those conditions which have been taken as the basis of the formula and discharge tables.

The water passes through the weir box with a rather high velocity, but the velocity varies with the head, and the slope of the water surface changes accordingly. The extent of the draw-down curve also varies with the head and length of weir crest and it was therefore necessary to fix the point at which to take the head. Several measurements of draw-down curves resulted in choosing a point 6 feet back from the plane of the weir, which would be away from any considerable influence of draw-down for the weirs used in the experiments, and would not include much of the slope of the water surface.

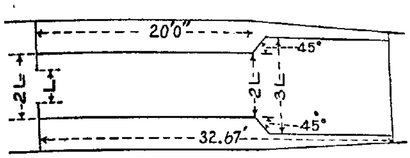

Fig. 5.—Plan of experimental weir box for No. 17, Table I.

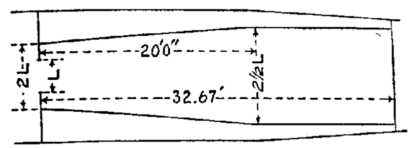

Fig. 6.—Plan of experimental weir box for No. 19, Table I.

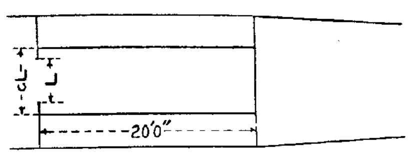

Fig. 7.—Plan of experimental weir box for Nos. 21, 22, 24, and 25, Table I.

A total of 277 experiments were made on this new type of weir, which for want of a better name is called an "irrigation weir," and of this number 101 were preliminary tests and 176 were made under standard conditions.

DEDUCTIONS FROM EXPERIMENTS

The individual equations in simple form for each set of experiments and the conditions under which those experiments were made are given in Table I. The following deductions have been obtained from comparisons of the equations stated in the table, the bottom contractions being entirely suppressed in all cases, but with various arrangements of sides of weir box.

For similar conditions of weir box, the coefficient c decreases as the length of weir crest L increases, and the exponent n increases as the length increases.

As the width of weir box, or end contractions, is increased for any certain length of weir, both c and n decrease. This is probably due to a decrease in the velocity of approach, owing to the increased area of the weir box.

When the sides of the weir box are parallel, the discharge increases as the width of the box is decreased, for all sizes of weirs.

The greatest discharge is obtained when the sides of the weir box are parallel and it decreases as the angle between the sides becomes greater; or, stated in another way, the discharge increases as the sides become more nearly parallel, the width of the box at the weir remaining constant.

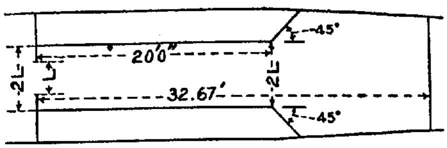

FIG. 8.—Plan of experimental weir box for No. 27, Table I.

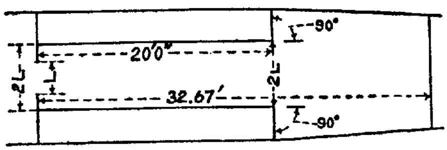

FIG. 9.—Plan of experimental weir box for No. 28, Table I.

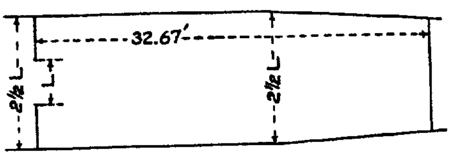

FIG. 10.—Plan of experimental weir box for No. 29, Table I.

When wings placed at the upper end of the weir box to form a junction between the sides of the box and the canal bank are changed from 90° to 45° with the axis of the channel, the discharge is increased for low heads, remains about the same for heads of 0.7 foot, and is decreased for high heads. The percentage of change in discharge due to such a change in the wings is greater when the sides of the weir box are parallel.

The ratio of discharge to length of weir decreases as the length of the weir increases; or, in other words, the discharge over a 4-foot weir is less than four times the discharge over a 1-foot weir, as is shown by the individual standard equations, Nos. 30 to 34, in Table I. This is the reverse of the condition found in rectangular weirs having complete end and bottom contractions and negligible velocity of approach.[1]

If the sides of the weir box are continued parallel from a point 20 feet upstream from the plane of the weir (fig. 6), instead of being continued

[1] Cone, V. M. Flow through weir notches with thin edges and full contractions. *In* Jour. Agr. Research, v. 5, no. 23, p. 1051–1114. 1916.

at the same angle as the other part of the weir box (fig. 2), the discharge will be increased about one-third of 1 per cent for 1-foot head and decreased about 1 per cent for 0.2-foot head, as indicated for the 3-foot weir in Nos. 19 and 33 in Table I.

In addition to the experiments with regular weir notches, three sets of experiments were made with 90° triangular notches having suppressed bottom contraction and different end contractions. The results are represented by Nos. 35, 36, and 37 in Table I. The logarithmic discharge curve for the 90° triangular notch with complete end and bottom contractions is a perfect straight line represented by the equation $Q=2.487h^{2.4806}$. Suppression of the bottom contraction, No. 35 in Table I, resulted in changing the logarithmic discharge curve from a straight line to a curved line, and increased the discharge. An average straight line drawn through the discharge data, represented by the equation $Q=2.541h^{2.492}$, agrees with the experimental data for medium heads, but is about 1 per cent low for high and low heads.

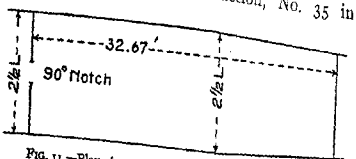

FIG. 11.—Plan of experimental weir box for No. 35, Table I.

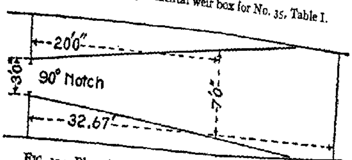

FIG. 12.—Plan of experimental weir box for No. 36, Table I.

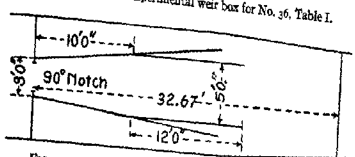

FIG. 13.—Plan of experimental weir box for No. 37, Table I.

The second set of experiments, No. 36 in Table I, also gave a logarithmic plot which was a curved line. The average straight line for these data was about 1 per cent low for heads of 0.3 and 1.3 feet, and about 2 per cent high for heads of approximately 0.8 foot. This indicates the curvature of the discharge plot to be increased by a decrease in end-contraction distances.

The third set of experiments, No. 37 in Table I, was made under conditions which practically amounted to making the weir box 10 feet shorter than in the previous case, having the sides of the carrying channel parallel in both cases, but closer together in this set of experiments. This had little effect upon the discharge in the aggregate, but changed the slope of the discharge curve slightly.

The 90° triangular notch with full contractions is one of the most accurate and reliable measuring devices for small quantities of water.

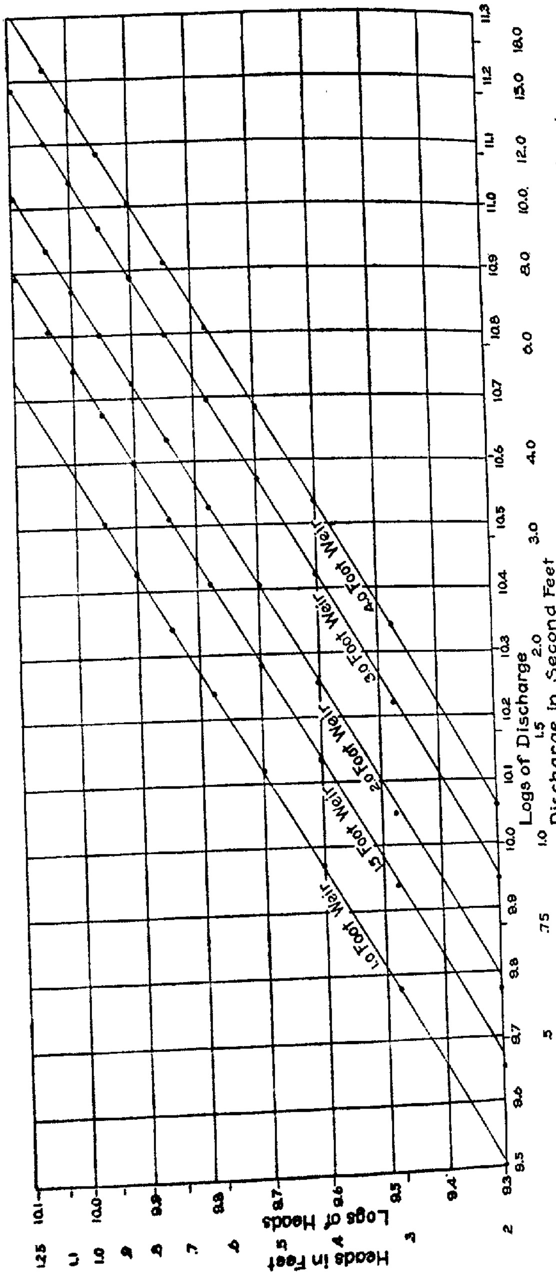

FIG. 14.—Experimental discharge data plotted logarithmically and curves drawn from values computed from standard equation for new irrigation weir.

Suppressing the contractions completely or in part changes the law of discharge through the triangular notch, decreases its accuracy as a practical measuring device, and does not insure the complete removal of sand and silt from the box. It is therefore an open question whether the advantages resulting from suppressed contractions with the triangular notch would not be more than counterbalanced by the inaccuracies introduced. The data are given without recommendation, but may be desirable for use in special cases.

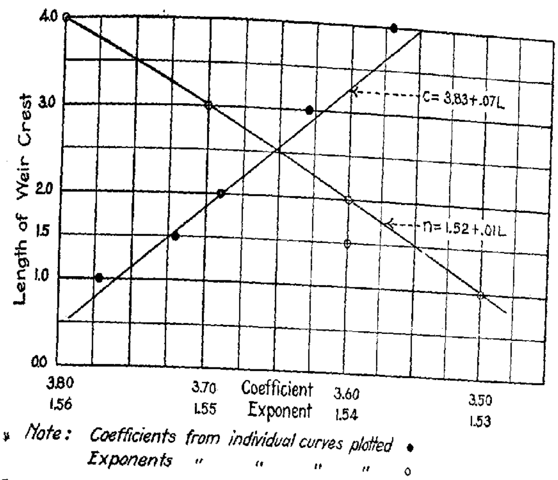

FIG. 15.—Coefficient and exponent values of individual discharge equations plotted against weir length.

DERIVATION OF WEIR FORMULA

The experimental discharge data for the standard weir conditions were plotted logarithmically for weirs having actual crest lengths of 1.0055, 1.5026, 2.0057, 2.9970, and 4.0056 feet, as shown in figure 14. These points do not lie on a straight line. An average straight line drawn through the points will give values too small for medium heads and too large for low and high heads. This characteristic of the curve is the reverse of the curve for rectangular weirs with full contractions, but the suppression of the bottom contraction and partial suppression of the end contraction has tended to straighten the discharge curve.

With full-contraction weirs and quite complete pondage, the head can be accurately determined and there is, therefore, ample reason for using a complicated formula to secure that accuracy of measurement, but the high velocity of water and wave action which occurs in the new irrigation weir preclude the possibility of determining the head accu-

rately enough to warrant any great refinement of the discharge formula. The assumption of straight-line logarithmic formulas is within 1 or 2 per cent of all the discharge data, with the exception of a few high and low heads; and since this is comparable to the accuracy expected under field conditions, such formulas were used to avoid more complicated equations.

The equations of the average straight lines through the plotted points are given in Table I, Nos. 30 to 34, inclusive. The exponent and coefficient values for these individual equations were then plotted against the weir crest lengths, as shown in figure 15. For simplicity the law of the

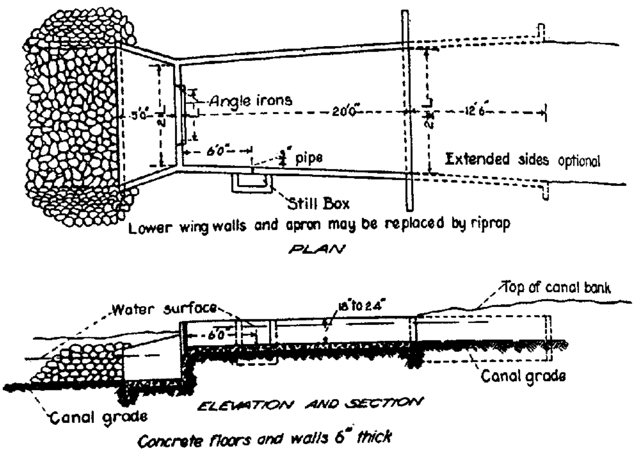

FIG. 16.—Plan, elevation, and section (standard) of new irrigation weir box.

coefficient values was assumed to be represented by the equation $c=(3.83-0.07L)$. The exponents, with the single exception of that for the 1.5-foot weir, fell on the straight line which has the equation $n=(1.52+0.01L)$. By substituting these expressions in the fundamental formula, $Q=cLh^n$, the general formula for the new irrigation weir was obtained

$$Q=(3.83-0.07L)Lh^{(1.52+0.01L)}$$

The straight-line curves drawn in figure 14 for each length of weir represent discharge values computed from the above formula and show graphically the agreement of the formula with the experimental data. The computed discharges are given in Table II.

TABLE II.—*Computed discharges for the new irrigation weirs*

[Computed from the formula $Q = (3.83 - 0.07\,L)\,L h^{(1.52+0.01\,L)}$]

Head.	Head.		Length of weir crest.				
			1 foot.	1.5 feet.	2 feet.	3 feet.	4 feet.
Feet.	*Ft.*	*in.*					
0.20	0	2 3/8	0.320	0.472	0.619	0.896	1.15
.21	0	2 1/2	.345	.509	.667	.966	1.24
.22	0	2 5/8	.371	.547	.717	1.04	1.34
.23	0	2 3/4	.397	.586	.768	1.11	1.43
.24	0	2 7/8	.424	.625	.820	1.19	1.53
.25	0	3	.451	.665	.873	1.27	1.63
.26	0	3 1/8	.479	.707	.927	1.34	1.74
.27	0	3 1/4	.507	.749	.982	1.43	1.84
.28	0	3 3/8	.536	.792	1.04	1.51	1.95
.29	0	3 1/2	.566	.836	1.10	1.59	2.06
.30	0	3 5/8	.596	.880	1.16	1.68	2.17
.31	0	3 3/4	.626	.926	1.22	1.77	2.28
.32	0	3 13/16	.658	.972	1.28	1.86	2.40
.33	0	3 15/16	.690	1.02	1.34	1.95	2.52
.34	0	4 1/16	.722	1.07	1.40	2.04	2.64
.35	0	4 3/16	.754	1.12	1.47	2.13	2.76
.36	0	4 5/16	.788	1.16	1.53	2.23	2.88
.37	0	4 7/16	.822	1.21	1.60	2.33	3.01
.38	0	4 9/16	.856	1.27	1.66	2.42	3.14
.39	0	4 11/16	.890	1.32	1.73	2.52	3.27
.40	0	4 13/16	.925	1.37	1.80	2.62	3.40
.41	0	4 15/16	.961	1.42	1.87	2.73	3.53
.42	0	5 1/16	.997	1.48	1.94	2.83	3.67
.43	0	5 3/16	1.03	1.53	2.01	2.94	3.81
.44	0	5 1/4	1.07	1.58	2.08	3.04	3.94
.45	0	5 3/8	1.11	1.64	2.16	3.15	4.09
.46	0	5 1/2	1.15	1.70	2.23	3.26	4.23
.47	0	5 5/8	1.18	1.75	2.31	3.37	4.37
.48	0	5 3/4	1.22	1.81	2.38	3.48	4.52
.49	0	5 7/8	1.26	1.87	2.46	3.59	4.67
.50	0	6	1.30	1.93	2.54	3.71	4.82
.51	0	6 1/8	1.34	1.99	2.62	3.82	4.97
.52	0	6 1/4	1.38	2.05	2.70	3.94	5.12
.53	0	6 3/8	1.42	2.11	2.78	4.06	5.27
.54	0	6 1/2	1.46	2.17	2.86	4.18	5.43
.55	0	6 5/8	1.51	2.23	2.94	4.30	5.59
.56	0	6 3/4	1.55	2.29	3.02	4.42	5.75
.57	0	6 13/16	1.59	2.36	3.11	4.54	5.91
.58	0	6 15/16	1.63	2.42	3.19	4.67	6.07
.59	0	7 1/16	1.68	2.49	3.27	4.79	6.23
.60	0	7 3/16	1.72	2.55	3.36	4.92	6.40
.61	0	7 5/16	1.76	2.62	3.45	5.05	6.57
.62	0	7 7/16	1.81	2.68	3.53	5.18	6.74
.63	0	7 9/16	1.85	2.75	3.62	5.31	6.91
.64	0	7 11/16	1.90	2.82	3.71	5.44	7.08
.65	0	7 13/16	1.95	2.88	3.80	5.57	7.25
.66	0	7 15/16	1.99	2.95	3.89	5.70	7.43
.67	0	8 1/16	2.04	3.02	3.98	5.84	7.60
.68	0	8 3/16	2.08	3.09	4.08	5.97	7.78
.69	0	8 1/4	2.13	3.16	4.17	6.11	7.96

TABLE II.—*Computed discharges for the new irrigation weirs*—Continued

Head.	Head.		Length of weir crest.				
			1 foot.	1.5 feet.	2 feet.	3 feet.	4 feet.
Feet.	*Ft.*	*in.*					
0.70	0	8 3/8	2.18	3.23	4.26	6.25	8.14
.71	0	8 1/2	2.23	3.30	4.35	6.39	8.32
.72	0	8 5/8	2.27	3.37	4.45	6.53	8.50
.73	0	8 3/4	2.32	3.45	4.55	6.67	8.69
.74	0	8 7/8	2.37	3.52	4.64	6.81	8.88
.75	0	9	2.42	3.59	4.74	6.95	9.06
.76	0	9 1/8	2.47	3.67	4.84	7.10	9.25
.77	0	9 1/4	2.52	3.74	4.94	7.24	9.44
.78	0	9 3/8	2.57	3.82	5.03	7.39	9.64
.79	0	9 1/2	2.62	3.89	5.13	7.54	9.83
.80	0	9 5/8	2.67	3.97	5.23	7.68	10.02
.81	0	9 3/4	2.72	4.04	5.34	7.83	10.22
.82	0	9 13/16	2.78	4.12	5.44	7.98	10.42
.83	0	9 15/16	2.83	4.20	5.54	8.14	10.62
.84	0	10 1/16	2.88	4.28	5.64	8.29	10.82
.85	0	10 3/16	2.93	4.35	5.75	8.44	11.02
.86	0	10 5/16	2.99	4.43	5.85	8.60	11.22
.87	0	10 7/16	3.04	4.51	5.95	8.75	11.43
.88	0	10 9/16	3.09	4.59	6.06	8.91	11.63
.89	0	10 11/16	3.15	4.67	6.17	9.07	11.84
.90	0	10 13/16	3.20	4.75	6.27	9.22	12.05
.91	0	10 15/16	3.25	4.83	6.38	9.38	12.26
.92	0	11 1/16	3.31	4.92	6.49	9.54	12.47
.93	0	11 3/16	3.36	5.00	6.60	9.70	12.68
.94	0	11 1/4	3.42	5.08	6.71	9.87	12.89
.95	0	11 3/8	3.48	5.16	6.82	10.03	13.11
.96	0	11 1/2	3.53	5.25	6.93	10.19	13.32
.97	0	11 5/8	3.59	5.33	7.04	10.36	13.54
.98	0	11 3/4	3.65	5.42	7.15	10.53	13.76
.99	0	11 7/8	3.70	5.50	7.27	10.69	13.98
1.00	1	0	3.76	5.59	7.38	10.86	14.20
1.01	1	0 1/8	3.82	5.67	7.49	11.03	14.42
1.02	1	0 1/4	3.88	5.76	7.61	11.20	14.64
1.03	1	0 3/8	3.93	5.85	7.72	11.37	14.87
1.04	1	0 1/2	3.99	5.93	7.84	11.54	15.10
1.05	1	0 5/8	4.05	6.02	7.96	11.71	15.32
1.06	1	0 3/4	4.11	6.11	8.07	11.89	15.55
1.07	1	0 13/16	4.17	6.20	8.19	12.06	15.78
1.08	1	0 15/16	4.23	6.29	8.31	12.24	16.01
1.09	1	1 1/16	4.29	6.38	8.43	12.41	16.24
1.10	1	1 3/16	4.35	6.47	8.55	12.59	16.48
1.11	1	1 5/16	4.41	6.56	8.66	12.77	16.71
1.12	1	1 7/16	4.47	6.65	8.79	12.94	16.95
1.13	1	1 9/16	4.53	6.74	8.91	13.12	17.18
1.14	1	1 11/16	4.59	6.83	9.03	13.30	17.42
1.15	1	1 13/16	4.66	6.92	9.15	13.49	17.66
1.16	1	1 15/16	4.72	7.02	9.28	13.67	17.90
1.17	1	2 1/16	4.78	7.11	9.40	13.85	18.14
1.18	1	2 3/16	4.84	7.20	9.52	14.04	18.38
1.19	1	2 1/4	4.91	7.30	9.65	14.22	18.63

TABLE II.—*Computed discharges for the new irrigation weirs*—Continued

Head.	Head.		Length of weir crest.				
			1 foot.	1.5 feet.	2 feet.	3 feet.	4 feet.
Feet.	*Ft.*	*in.*					
1.20	1	2⅜	4.97	7.39	9.77	14.41	18.87
1.21	1	2½	5.03	7.49	9.90	14.59	19.12
1.22	1	2⅝	5.10	7.58	10.02	14.78	19.36
1.23	1	2¾	5.16	7.68	10.15	14.97	19.61
1.24	1	2⅞	5.23	7.77	10.28	15.16	19.86
1.25	1	3	5.29	7.87	10.41	15.35	20.11

Table III shows the differences between the discharges computed from the formula and those obtained by experiment, these differences being expressed in cubic feet per second and in percentages. The formula agrees with the experimental data within a maximum amount of 4.8 per cent for an individual point, but this discrepancy is no doubt due partly to experimental inaccuracy and partly to the assumption of a straight-line formula. Medium heads give values for discharges that agree within 1 per cent, but the high and low heads will have a somewhat greater error. The formula agrees with the average straight lines drawn through the experimental data within a maximum error of 1 per cent. The error is greatest with the small weirs, decreases as the length of the weir increases, and for a length of 4 feet the error is quite small. Although the formula is derived from experiments with weirs having a maximum length of 4 feet it seems probable that the formula will be even closer for weirs with greater crest lengths.

TABLE III.—*Difference between discharges computed from the formula $Q=[3.83-0.07L]LH^{(1.52+0.01L)}$ and those obtained by experiment, for the new type of weir*

1-FOOT WEIR

Head.	Observed Q corrected true for length.	Computed Q.	Difference in Q.	Percentage of difference.[1]
Feet.				
0.200	0.314	0.320	+0.006	+1.94
.300	.595	.596	+.001	+.17
.400	.935	.925	+.010	+1.07
.500	1.299	1.302	+.003	+.20
.599	1.727	1.716	−.011	−.60
.699	2.183	2.174	−.009	−.40
.800	2.661	2.673	+.012	+.50
.895	3.113	3.173	+.060	+1.92

[1] Percentage of difference between discharge obtained by computations from the formula
$$Q=[3.83-0.07L]LH^{(1.52+0.01L)}$$
and by experiment, the bases of comparison being the experimental data.

TABLE III.—*Difference between discharges computed from the formula $Q=[3.83-0.07L]LH^{(1.52+0.01L)}$ and those obtained by experiment, for the new type of weir*—Continued

Head.	Observed Q corrected true for length.	Computed Q.	Difference in Q.	Percentage of difference.
1.5-FOOT WEIR				
Feet.				
0.199	0.448	0.469	+0.021	+4.69
.299	.865	.876	+ .011	+1.30
.400	1.360	1.369	+ .009	+ .66
.497	1.907	1.910	+ .003	+ .16
.600	2.560	2.551	− .009	− .35
.700	3.227	3.232	+ .005	+ .15
.800	3.956	3.967	+ .011	+ .28
.900	4.728	4.753	+ .025	+ .53
.998	5.521	5.570	+ .049	+ .89
1.099	6.378	6.459	+ .081	+1.27
1.250	7.727	7.870	+ .143	+1.85
2-FOOT WEIR				
0.200	0.590	0.619	+0.029	+4.80
.300	1.116	1.156	+ .040	+3.58
.400	1.784	1.800	+ .016	+ .90
.500	2.536	2.538	+ .002	+ .08
.600	3.358	3.361	+ .003	+ .09
.700	4.288	4.261	− .027	− .63
.800	5.179	5.234	+ .055	+1.06
.900	6.279	6.274	− .005	− .08
1.000	7.358	7.380	+ .022	+ .30
1.100	8.540	8.547	+ .007	+ .08
1.250	10.335	10.406	+ .071	+ .69
3-FOOT WEIR				
0.200	0.884	0.896	+0.012	+1.36
.300	1.663	1.680	+ .017	+1.02
.396	2.583	2.584	+ .001	+ .04
.501	3.720	3.720	.000	.00
.598	4.938	4.895	− .043	− .85
.700	6.297	6.248	− .049	− .78
.800	7.754	7.684	− .070	− .90
.900	9.287	9.223	− .064	− .69
1.001	10.948	10.877	− .071	− .65
1.100	12.638	12.589	− .049	− .39
1.250	15.331	15.347	+ .016	+ .10

TABLE III.—*Difference between discharges computed from the formula $Q=[3.83-0.07L]LH^{(1.52+0.01L)}$ and those obtained by experiment, for the new type of weir*—Continued

4-FOOT WEIR

Head.	Observed Q corrected true for length.	Computed Q.	Difference in Q.	Percentage of difference.
Feet.				
0.200	1.148	1.153	+0.005	+0.44
.301	2.188	2.182	-.006	-.27
.399	3.417	3.387	-.030	-.88
.500	4.806	4.817	+.011	+.23
.601	6.427	6.417	-.010	-.16
.700	8.158	8.141	-.017	-.21
.799	10.045	10.006	-.039	-.39
.900	12.081	12.047	-.034	-.28
1.000	14.194	14.200	+.006	+.04
1.100	16.426	16.476	+.050	+.30

SPECIFICATIONS FOR CONSTRUCTION AND USE OF THE NEW IRRIGATION WEIR

A plan and elevation of the standard weir is shown in figure 16. The weir notch is rectangular in form, with sharp crest and sides. The floor of the weir box must be level with the crest, and it is therefore convenient to use an angle iron for the crest, embedding one face of the angle until flush with the surface of the floor, the other face of the angle extending downward. The sides of the weir notch may also be made of angle iron placed in a vertical position, with one end extending below the crest and one face of the angle against the angle-iron crest. The angle can then be attached to the weir bulkhead through holes placed in the other face. This arrangement is durable and inexpensive and will meet the requirement of sharp crest and full lateral expansion for the escaping stream of water. The grade of the canal downstream from the weir must be low enough to give free fall and complete aeration to the nappe.

The floor of the weir box must be level throughout, and there must be no sudden or decided differences in elevation between the floor and the grade of the channel of approach. The weir box must be placed in the center of the ditch, so the axial line of the box corresponds with the axial line of the canal, in order that the water may enter the weir box in straight lines. The width of the weir box must be twice the length of the weir crest ($2L$) at the plane of the weir, and two and a half times the length of the weir crest ($2\frac{1}{2}L$) at a distance of 20 feet upstream from the plane of the weir. The standard tests were made with a weir box 32.5 feet long, except for the 4-foot weir, No. 34, Table I, and the sides were extended at the angle indicated above. However, from Table I, Nos. 7, 8, and 9,

and 10, 11, and 30, it will be seen that for the 1-foot weir at least the discharge through a box 32.5 feet long with sides set to the standard dimensions is within 1 per cent of the discharge obtained by placing 90° wings at the end of a similar box 20 feet long. The use of 45° wings will cause an error of about 2½ per cent. Therefore the weir box for the new irrigation weir should be made with sides spaced 2 L at the plane of the weir and 2½ L at 20 feet upstream from the weir, with the sides continuing at this angle until they meet the banks of the ditch or canal; or the box should be only 20 feet long with wings to connect the sides of the box with the canal banks, and these wings should form an angle of 90° with the axis of the weir box. The 90° wings (fig. 2) give a discharge about 1 per cent greater than with the extended sides (fig. 4) for a head of 0.2 foot and about 1 per cent less for a head of 1 foot.

Extending the sides of the weir box until they are the full size of the canal will give more accurate results, but this accuracy may not be required, and the saving in cost of construction due to the shorter length of the weir box with wings may be more desirable than the 1 per cent of accuracy in measuring the water. Unless the canal bottom is easily eroded or scoured, it would not be necessary to extend the floor of the weir box beyond 20 feet, even if the sides of the box are extended.

The comparatively high velocity of the water flowing through the weir box causes a wave action and generally disturbed condition of the water surface, which makes it quite impossible to determine the head h in the open weir box. Any stilling device placed in the weir would interfere with the action of the weir, and it is therefore necessary that a still box be placed outside the weir box and connected through the side of the weir box with one or more 1-inch pipes located 6 feet from the plane of the weir. The pipe should be placed near the floor of the weir box to insure its being submerged for low heads, and care must be used to place the pipe normal to the side of the weir box, and not normal to the axis of the box. If the pipe is pointed downstream the velocity of the water in the weir box will cause a suction action which will make the water surface in the still box lower than that in the weir box. If the pipe is pointed upstream, there will be a velocity head added to the actual water level in the weir box, and the water in the still box will be higher than that in the weir box. Although no sand or silt will accumulate in the weir box, regardless of the amount carried by the stream, silt may be deposited in the still box and clog the connection pipe unless it is cleaned regularly. By making a deep still box, space will be provided for such silt accumulation and therefore less frequent cleaning will be required. The still box should have inside dimensions of at least 1 foot by 1½ or 2 feet, with such depth as is necessary. The head in the still box may be determined by means of a scale, a hook gauge, or an automatic registering gauge.

The new irrigation weir may be constructed of lumber, but the design is such that it may be easily constructed of concrete. There would be

no difficult form work required for the concrete, and it would make an inexpensive, durable, and satisfactory measuring device, especially if the angle-iron sides and crest of notch were used in connection with the concrete box.

ADVANTAGES OF THE NEW IRRIGATION WEIR

(1) The new irrigation weir is self-cleaning. The increasing velocity of the water from the time it enters the weir box until it passes through the weir notch prevents the deposit of sand and silt. Floating materials are also carried through the weir.

(2) No lowering of the canal grade or building up of the banks is required for the construction of the weir box. The weir box has only one-fourth the depth and a less width than is required for a full-contraction weir. Less excavation and less materials are needed in the construction, and the cost of the weir is therefore greatly decreased.

(3) It may be installed by the farmer without expert assistance and with the tools ordinarily at hand. Its operation does not require special training.

(4) Its accuracy is consistent with practical demands and will remain constant.

(5) It can not be easily tampered with or accidentally injured so as to alter its discharge.

(6) There are no working parts which require attention for proper operation. There is practically no upkeep expense if the weir is well constructed of durable materials.

(7) When the discharge tables are used, no computations are required, because the effect of velocity of approach is incorporated in the tables. The weir discharge is expressed in cubic feet per second, which may be converted into any units desired. An automatic recording gauge used in connection with this weir will give a record of the quantity of water discharged at all times, and the aggregate discharge can be computed from the record if desired.

(8) It is not patented, and the entire cost of the weir is for materials and the labor of construction.